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Research Article

Assessment of macroalgae coverage in a scarcely studied deep rocky reef in the tropical eastern Mexican Pacific

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ABSTRACT. The biodiversity of epibenthic communities in rocky reefs in the Mexican tropical Pacific has been studied minimally during the past three decades. This study describes the abundance and distribution of algae and invertebrates in a deep rocky reef from this region. Samples were taken at 20 m depth in 2012 by randomly placing 50×50 cm quadrats. Also, photographs were taken of each quadrat to quantify the coverage of organisms. Throughout the study, the algae were the most abundant group (17748.5 cm m^{-2}), of which encrusting calcified (6350.9 cm m^{-2}), turf (3040.3 cm m^{-2}), and larger-sized articulated corallines (2700.9 cm m^{-2}) had the highest coverage. Regarding invertebrates, zoanthids (1153.3 cm m^{-2}) and corals (746.7 cm m^{-2}) had high coverage. All of the algal groups were found on vertical and horizontal substrates. The detrended correspondence analysis showed that larger-sized articulated corallines and encrusting not calcified groups were prevalent on the horizontal substrate and corals on the vertical substrate. These abundance and distribution patterns represent the first quantitative study of rocky reefs from the region. Considering the rapid influence of human activities in this coastal zone and the fact that rocky reefs have been minimally studied, there is a clear need for long-term monitoring programs to establish reef communities' patterns and processes, which are useful in conservation programs.

Keywords: rocky reefs; deep subtidal communities; macroalgae; turfs; tropical marine biodiversity

INTRODUCTION

Rocky reefs comprise one of the most important ecosystems in coastal areas due to their high levels of biodiversity and productivity (Irving & Connell 2002, Piazzi et al. 2004, Balata & Piazzi 2008, Portugal et al. 2017, Spector & Edwards 2020). These ecosystems provide essential functions, serving as sites for larval dispersion, breeding, refuge, feeding, reproduction, recruitment, and habitat for economically significant species; they also provide numerous environmental services. For example, they supply habitat and food for other marine organisms, provide protection from disturbances for people, and support cultural services for tourists, recreational divers, and scientists, as well as their aesthetic value to photographers and other artists (Virgilio et al. 2006, Santander-Monsalvo et al. 2018, Hoffmann et al. 2022). In addition, they are economically valuable for fishing and tourism. However, the consequences of these activities have created pollution, habitat fragmentation, overfishing, the introduction of exotic species, sedimentation, diseases, and death (Santander-Monsalvo et al. 2018, Edwards & Konar 2020).

Rocky reefs have been studied around the world with diverse aims (Airoldi & Cinelli 1997, Barros et al.

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2001, Piazzi & Cinelli 2001, Piazzi et al. 2002, Balata et al. 2006, 2007a,b, Wernberg & Connell 2008, Glasby et al. 2017, Cordero-Umaña & Santidrián-Tomillo 2020, Bell et al. 2022, Canessa et al. 2022, Martinez et al. 2022). Reef ecosystems are widely distributed throughout Mexico's temperate and tropical coastal areas. They are ecologically important; almost half of them are protected by the federal government under the Natural Protected Area scheme. Coral reefs are more commonly protected under this system, while the rocky reefs of the Pacific coast are excluded, specifically those located in the tropical Pacific region (Santander-Monsalvo et al. 2018). In coastal areas in the Mexican Pacific, the greatest number of studies have been performed in the temperate and temperate-tropical transition regions (Carreón-Palau et al. 2003, Casas-Valdéz & Aguila-Ramírez 2008, Castañeda-Fernández et al. 2010, Ulate et al. 2016, Favoretto et al. 2022). In the tropical region, studies have been performed mainly in rocky intertidal and shallow subtidal areas (León-Tejera & González-González 1994, Mendoza-González & Mateo-Cid 1998, Ávila-Ortiz & Pedroche 2005, Rodríguez et al. 2008, Mendoza-González et al. 2011, Mateo-Cid & Mendoza-González 2012, Mendoza-González et al. 2018), mostly with a floristic or taxonomic approach, leaving deep rocky reefs essentially unexplored, principally due to logistical and funding limitations.

Hence, these ecosystems are practically unknown in the Mexican tropical Pacific, specifically in Zihuatanejo's coastal areas. Salcedo-Martínez et al. (1988) carried out an inventory of macroalgae and invertebrates at nine locations in Zihuatanejo, six of which were rocky reefs, including the Sacramento deep rocky reef. Other research carried out in El Yunque, and La Ropa reefs described the structure of the macroalgal community (López et al. 2000) and the morphological variations of algal turfs (López et al. 2004). Therefore, this preliminary study aimed at determining the abundance and distribution of the epibenthic organisms on the Sacramento deep rocky reef.

MATERIALS AND METHODS

Study area

The study was carried out on the NW end of Bajo Sacramento (17°38'02''N, 101°36'39''W), located 3 km south of Ixtapa Bay, Guerrero State, Mexico (Fig. 1).

The climate is Aw, a warm sub-humid with summer rainfall (García 2004) with an average annual temperature of 25°C and an annual rainfall of 800-1600 mm. The predominant winds are SE in the rainy season and NW during the dry season. The Sacramento rocky reef is characterized by a pinnacle that emerges above the sea surface with vertical walls with a 70-90° slope; at a depth of 10 m, an extensive platform is formed that descends to a depth of 30 m. The topography in this zone is heterogeneous, and the bottom is composed of overlapping, irregularly shaped rocky blocks 1-5 m long, among which there are sand, gravel, and boulders deposits. The biggest rocks are cube-shaped with relatively flat upper faces. The smaller blocks exhibit a more irregular morphology. The site is exposed to strong internal currents, which produce laminar or turbulent flows of water that are stronger during the rainy and hurricane seasons.

Sampling

This study was performed in January, June, and October 2012 via SCUBA diving at 20 m depth. For each date, six 50×50 cm quadrats divided into 10×10 cm sub-quadrats were randomly placed on both vertical and horizontal substrates. Because of difficult environmental conditions, we could not sample two quadrats; thus, 16 quadrats were sampled (10 on the horizontal substrate and 6 on the vertical). Three 10×10 cm macroalgae samples were randomly collected by hand from each 50×50 cm quadrat using a hammer and chisel. In June, the adverse weather conditions did not allow the collection of samples; only photographs were taken. Samples were placed in plastic bags and taken to the laboratory for processing and taxonomic identification. The algal material was preserved in 4% formalin seawater.

All macroalgal species were identified following Dawson (1953, 1954, 1960, 1961, 1962, 1963a,b) and Taylor (1945). Photographs of each sub-quadrat (10×10 cm) of each quadrat (50×50 cm) were taken with a Canon 10, 15 MG camera to quantify the algal cover (cm m^{-2}). The algal cover was quantified by classifying morphological functional groups (Balata et al. 2011). This classification proposal results from the subdivision of the morphological functional groups of Steneck & Dethier (1994) based on the structure of the thallus, growth form, branching pattern, and taxonomic affinities. This expanded classification allowed the morphological functional groups to be quantified straightforwardly and reliably, corresponding with specific algal genera. Additionally, we included turf growth form as a useful descriptor of the assemblages of benthic organisms, which many authors around the world have employed because of its prevalence in benthic assemblages (Kendrick 1991, Airoldi 1998, 2000, Cheroske et al. 2000, Irving & Connell 2002,

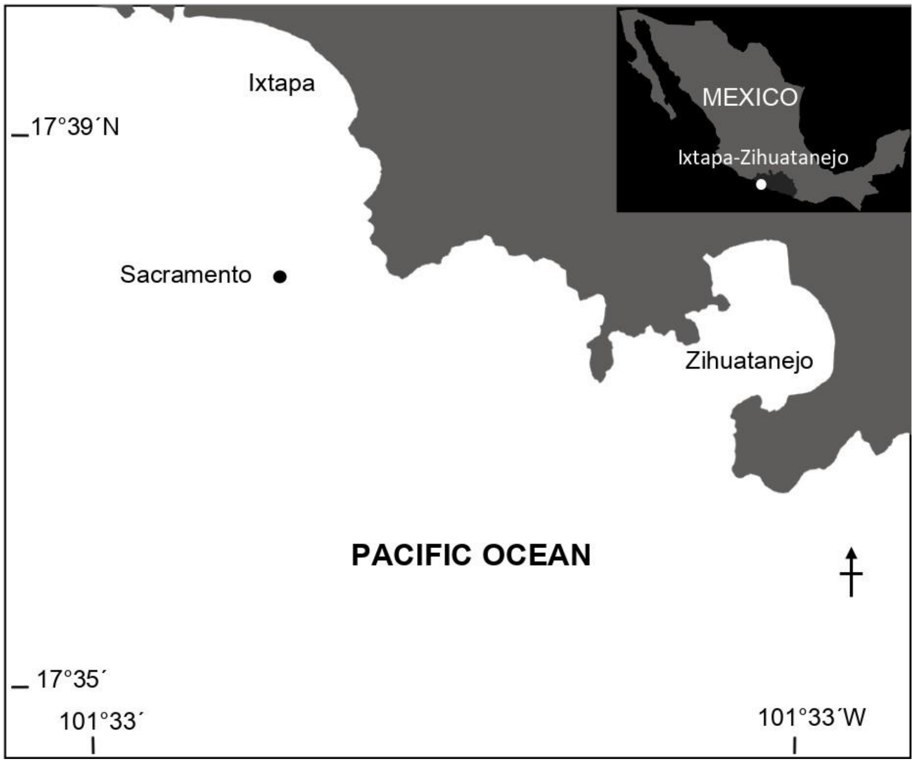

Figure 1. Study area. The upper map shows the location of Ixtapa-Zihuatanejo in Guerrero State. The lower map shows the location of Sacramento in Ixtapa-Zihuatanejo.

Coleman 2002, 2003, Prathep et al. 2003, Birrell et al. 2004, Kelaher & Castilla 2005, Batelli & Rindi 2008, Connell et al. 2014, Gowan et al. 2014, Harris et al. 2015, Short et al. 2015, Martins et al. 2016, López et al. 2017). We have also included the "tassel" category because it is very common in our study site. However, it has not been described in any previous classification. A tassel forms tufts composed of very thin, abundant filaments of cyanoprokaryotic algae with an intense red color and a soft texture. Because the presence of some macroinvertebrates was conspicuous, the coverage of large taxa such as Porifera (PO), Echinoidea, e.g. sea urchins (SU), Octocorallia-Alcyonacea (CO), Zoanthidae (ZO) and Ascidiacea (AS) was included (Brusca 1983). In cases when some epibiotic component could not be identified from a photograph, it was referred to as "unidentified" to quantify its coverage.

Statistical analysis

Based on the Kruskal-Wallis (K-W) test statistic, the significant differences between the coverages of morphological, functional groups of macroalgae were demonstrated for each substrate. Certain functional groups were not detectable on some sampling dates, so no differences were recorded. Different groups of organisms were used as ordering variables for the sampling quadrats to determine their significance based on the coverage in the two substrates studied. Using detrended correspondence analysis (DCA) (Hill & Gauch 1980, Gauch 1982) and the DECORANA program (PC-ORD 5), the different sampling quadrats obtained from the horizontal (H) and vertical (V) substrates during the year were ordered in a multidimensional space. Each quadrat is identified according to the coverage of the morphological functional groups of macroalgae.

RESULTS

From the total quadrats analyzed, 42 species of macroalgae were identified (Table 1), 29 Rhodophyta, 8 Chlorophyta, 5 Ochrophyta-Phaeophyceae, and 1 Cyanobacteria. These included the following morphological functional groups: encrusting calcified (EC), prostrate not strictly adherent to the substratum (PS), larger-sized articulated corallines (AR), encrusting not calcified (ENC), encrusting (ER), turf-forming algae (TU) and tassel (TA) (Table 1).

No significant differences were observed among study dates for many of the algal functional groups and

Table 1. Functional group of algal species and taxa of invertebrates of the Sacramento rocky reef.

Taxa	Functional group	Taxa	Functional group
Rhodophyta		**Chlorophyta**	
Acrochaetium sp.	TU	*Boodleopsis* sp.	TU
Amphiroa beauvoisii	AR	*Bryopsis pennata*	TU
Amphiroa misakiensis	AR	*Chaetomorpha antennina*	TU
Amphiroa rigida	AR	*Chlorodesmis* sp.	TU
Asparagopsis taxiformis	TU	*Cladophora microcladioides*	TU
Ceramium affine	TU	*Cladophora glomerata*	TU
Ceramium zacae	TU	*Derbesia marina*	TU
Ceratodictyon tenue	TU	*Derbesia tenuissima*	TU
Champia parvula	TU	**Ochrophyta-Phaeophyceae**	
Dasya sinicola var. *abyssicola*	TU	*Dictyopteris delicatula*	TU
Erythrotrichia carnea	TU	*Lobophora variegata*	PS
Gelidium pusillum	TU	*Neoralfsia* sp.	ER
Gracilaria sp.	TU	*Ralfsia pacifica*	ER
Halichrysis sp.	TU	*Sphacelaria rigidula*	TU
Halymenia cf *abyssicola*	TU	**Cyanoprokaryota**	
Herposiphonia litoralis	TU	*Oscillatoriaceae*	TA
Herposiphonia secunda	TU	**Invertebrate taxa**	
Hildenbrandia sp.	ENC	Porifera	PO
Hypnea pannosa	TU	Echinoidea (sea urchins)	SU
Hypnea johnstonii	TU	Octocorallia (Alcyonacea)	CO
Jania subpinnata	TU	Zoanthidae	ZO
Lejolisia colombiana	TU	Ascidiacea	AS
Lithophyllum sp.	EC		
Parviphycus antipae	TU		
Peyssonnelia rubra	PS		
Polysiphonia subtilissima	TU		
Porphyra sp.	TU		
Pterocladiella caloglossoides	TU		

invertebrate groups. Only significant differences in the H substrate for the EC group (KW-$H_{(2, 9)}$ = 5.8; P = 0.05) with a median of 4930 cm m^{-2} in January, 1840 cm m^{-2} in June and 3980 cm m^{-2} in October (Fig. 2), and marginal differences for the AR group (KW-$H_{(2, 9)}$ = 5.5; P = 0.06) with a median of 1784 cm m^{-2} in January, 2500 cm m^{-2} in June, and 1090 cm m^{-2} in October (Fig. 3).

An annual analysis of coverage variations was developed for the algal functional groups and invertebrate taxa by comparing both substrates. Only significant differences between H and V substrate for AR (KW-$H_{(1, 15)}$ = 3.55; P = 0.05) were observed, with a median for the H substrate of 2068 cm m^{-2} and the V substrate of 930 cm m^{-2} (Fig. 4).

Similarly, significant differences in the TA group (KW-$H_{(1, 7)}$ = 4.58; P = 0.03) with a median for the H substrate of 486 cm m^{-2} and the V substrate of 20 cm m^{-2} were observed (Fig. 5).

Finally, a group of invertebrates was observed, CO group (KW-$H_{(1, 8)}$ = 3.8; P = 0.05) with a median for the H substrate of 20 cm m^{-2}, and the V substrate of 620 cm m^{-2} (Fig. 6).

Several groups of macroalgae had notably different mean annual coverage values in the two substrates. TU and AR exhibited twice as much coverage on the H substrate compared to the V, and TA also showed very high coverage on the H. At the same time, it had the lowest coverage on the V substrate (Table 2). The ENC and ER groups of macroalgae exhibited double the coverage on the V substrate. The mean annual coverage of CO was high on the V substrate but very low on the H (Table 2).

The DCA ordered the samples and organism groups according to the substrate inclination. AR and ENC were characteristic of the H substrate (Kendall Tau = 0.70 and 0.54, respectively). The CO was distributed on the V substrate (Kendall Tau = 0.68 and 0.57) (Fig. 7).

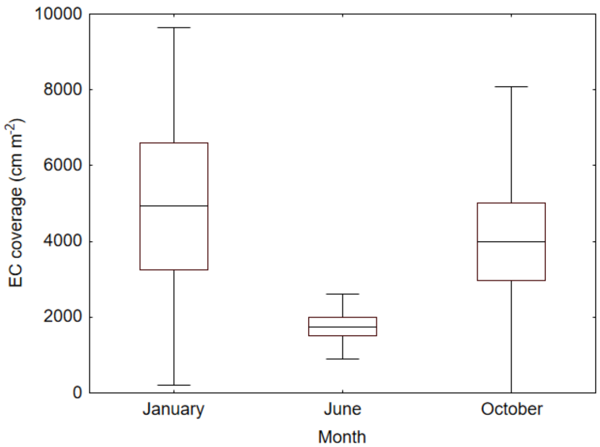

Figure 2. Coverage temporal variation of encrusting calcified (EC) on the horizontal substrate.

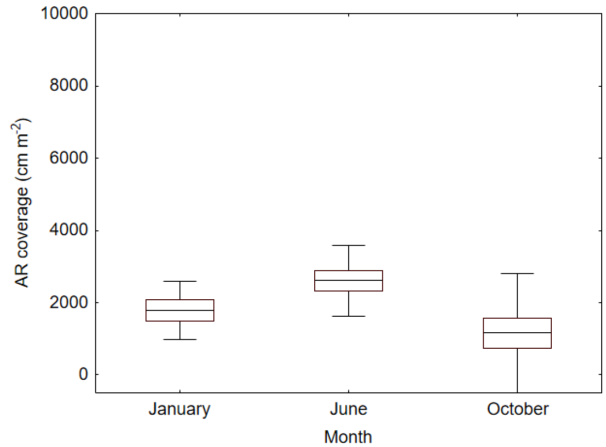

Figure 3. Coverage temporal variation of articulated corallines (AR) on the horizontal substrate.

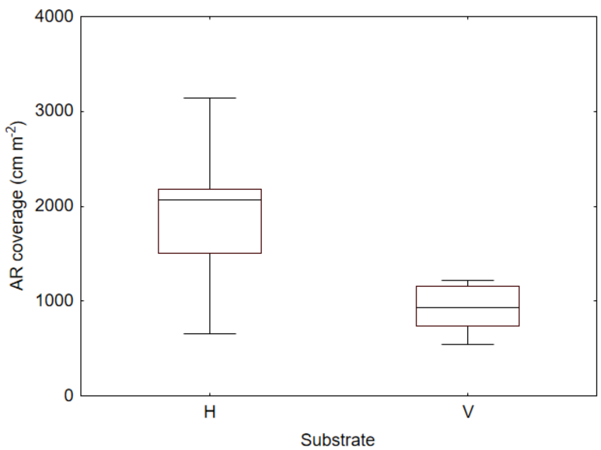

Figure 4. Total coverage of articulated corallines (AR) on the horizontal (H) and vertical (V) substrates.

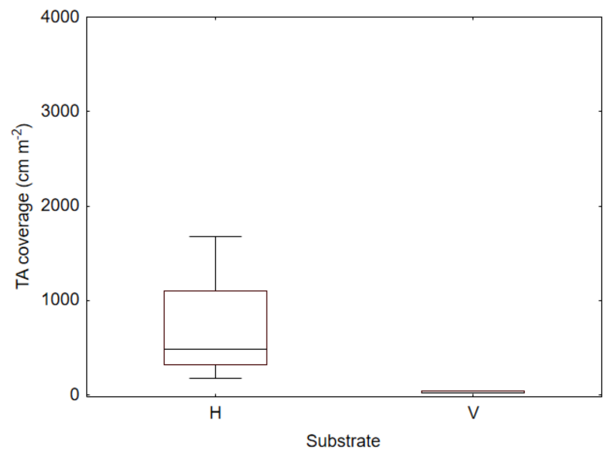

Figure 5. Total coverage of tassel algae (TA) on the horizontal (H) and vertical (V) substrates.

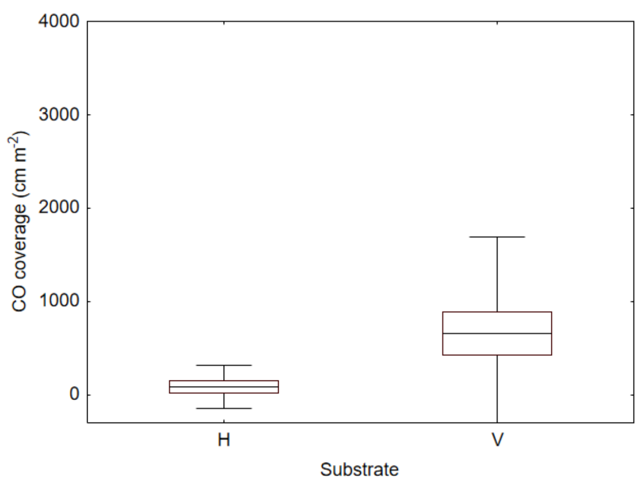

Figure 6. Total coverage of coral (CO) on the horizontal (H) and vertical (V) substrates.

Table 2. Average annual coverage and standard error of epibenthic organisms on horizontal and vertical substrates. *Samples from these groups were not collected. **Standard error was not obtained. PO: Porifera, SU: sea urchins, CO: Octocorallia-Alcyonacea, ZO: Zoanthidae, AS: Ascidiacea, EC: encrusting calcified, PS: prostrate not strictly adherent to the substratum, AR: larger-sized articulated corallines, ENC: encrusting not calcified, TU: turf-forming algae, TA: tassel, ER: encrusting.

Algae functional groups /invertebrate groups	Horizontal substrate ($cm\ m^{-2}$)	Vertical substrate ($cm\ m^{-2}$)
AR	1780.9 ± 295.2	920.0 ± 105.6
TU	2003.6 ± 294.5	1036.7 ± 527.9
EC	3377.6 ± 607.7	2973.3 ± 372.4
PS	914.7 ± 249.0	1307.0 ± 338.1
ENC	453.3 ± 213.6	980.0 ± **
ER	366.7 ± 77.2	900.0 ± 235.7
TA	708.0 ± 332.2	26.7 ± 6.7
PO	352.0 ± 90.7	164.0 ± 71.9
SU	120.0 ± 46.2	*
CO	86.7 ± 66.7	660.0 ± 230.1
AS	20.0 ± **	*
ZO	*	1153.3 ± 673.3
UN	148.0 ± 90.7	496.0 ± 247.8
Total	10331.5	10617.3

The DCA explained a variation with 0.88 inertia; the first axis contributed with a 0.27 eigenvalue, and the second axis with a 0.09 eigenvalue.

Figure 7 shows a larger number of quadrats placed on the horizontal bedrock clustered to the right of axis 1 in the eigenvector AR, while the other set of quadrats placed on the vertical bedrock, along with some from the horizontal bedrock, cluster to the upper right of the axis around the CO eigenvectors.

DISCUSSION

This work showed that the Sacramento rocky reef comprises a habitat that harbors significant algae biodiversity that was little known until now. Forty-two species of macroalgae were identified, exceeding the last number recorded in an inventory-type study of Sacramento (Salcedo-Martínez et al. 1988). They recorded just two species of macroalgae on the reef, *Halimeda discoidea* at 7 m depth and *Lithophyllum* sp. (reported as *Lithothamnium* sp.) at 25 m depth. The other rocky reef studied in the Zihuatanejo region is El Yunque, located 9 km from Sacramento with a depth of 12 m (López 1993, 1996, López et al. 2000).

The total number of macroalgae species in El Yunque was 38. Seventeen of these were also found in this work, including *Amphiroa misakiensis*, *A. beauvoisii*, *A. rigida*, *Champia parvula*, *Hypnea pannosa*, *Cladophora microcladioides*, *Derbesia marina*, *Dictyopteris delicatula*, *Lobophora variegata*, and *Ralfsia pacifica*.

The general pattern of coverage of organisms showed that algae were predominant throughout the study site, which contrasts with the low coverage of invertebrates. Based on their high coverage, the predominant algal functional groups were EC, TU, and AR. These groups and their representative taxa have also been found on other rocky reefs, mainly in the Mediterranean Sea (Airoldi & Virgilio 1998, Balata et al. 2005, 2006, 2007a, 2011, Virgilio et al. 2006). The encrusting calcified algae have a wide distribution in rocky littoral areas, from the intertidal and shallow subtidal zones up to 200 m deep. They are among the most abundant organisms on hard substrates with strong currents. Illumination is less than 0.1% surface (Steneck 1986, Björk et al. 2005). Although current and illumination were not measured at Sacramento, the wide distribution pattern in the V and H substrates and the high coverage of these algae coincide with reports from other regions. Therefore it is necessary to include these factors in subsequent studies to determine their influence.

The TU was the other predominant algal group based on coverage. In contrast to turfs described for other coastal areas around the world in which species such as *Womersleyella setacea* (Batelli & Rindi 2008) or a functional group like filamentous algae (Kendrick 1991, Airoldi et al. 1995) are predominant, the Sacramento rocky reef turfs are composed of multiple species of Rhodophyta, Chlorophyta, Phaeophyceae, and Cyanobacteria. There is no predominant species, functional group, or growth form. The TU at Sacramento had a height of <5 mm, agreeing with the only previous regional report from the coral reef at Las Gatas Beach (López et al. 2017). The algal turf species observed can be grouped within the algal functional groups proposed by Balata et al. (2011). *Ceramium* spp. and *Cladophora* spp. are grouped in filamentous algae, *Amphiroa* spp. in articulated algae, *Lithophyllum* sp. and *Neoralfsia* sp. are grouped into calcified encrusting algae, and non-calcified encrusting algae, respectively. *Hypnea pannosa* and *Champia parvula* belong to the group of corticate algae. The lack of previous studies of the Sacramento rocky reef does not permit a more detailed comparison of the algal turfs. The previously mentioned study at the El Yunque rocky reef was a floristic work that did not include functional groups or growth forms. The turfs are widely distributed in nume-

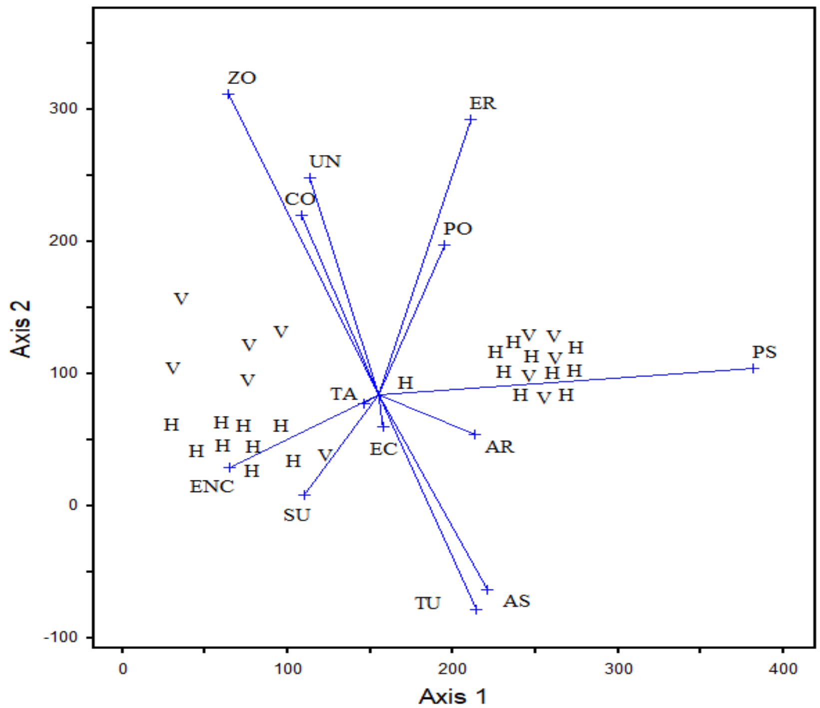

Figure 7. Detrended correspondence analysis (DCA) for the samples of algal functional groups and taxa of invertebrates on the horizontal (H) and vertical (V) substrates. PO: Porifera, SU: sea urchins, CO: Octocorallia-Alcyonacea, ZO: Zoanthidae, AS: Ascidiacea, EC: encrusting calcified, PS: prostrate not strictly adherent to the substratum, AR: larger-sized articulated corallines, ENC: encrusting not calcified, TU: turf-forming algae, TA: tassel, ER: encrusting.

rous temperate (Antoniadou & Chintiroglou 2005, Balata et al. 2005, Wallenstein et al. 2008) and tropical (Hay 1981, Birrell et al. 2004, Gowan et al. 2014, Sura et al. 2019) coastal areas. Their presence is mainly attributed to high concentrations of sedimentation and nutrients and reduced herbivory (Sura et al. 2019). In Sacramento, these factors may play an important role in the distribution and abundance of this algal growth.

Regarding the invertebrates, it was notable that ZO was only found on the vertical substrate, in contrast to SU and AS, which were found only on the horizontal. In other deep ecosystems, such as the biogenic reefs in the Mediterranean, it has also been found that specific communities of organisms exist as a function of the incline of the substrate (Cocito et al. 2002, Piazzi et al. 2002, Virgilio et al. 2006). The invertebrate taxa reported in this study agreed with reports from other temperate rocky and coralligenous locations (Balata et al. 2005). The deep, rocky habitats of the Mexican Pacific are practically unstudied, as compared to those in temperate regions, where it has been determined that various physical factors influence the diversity of organisms as sedimentation, hydrodynamics, nutrients, the slope of the substrate, and topography (Antoniadou & Chintiroglou 2005, Balata et al. 2006, 2007a). These factors vary as a function of depth. In most sublittoral ecosystems, it is a common phenomenon that determines the structure of the assemblages (Garrabou et al. 2002, Bell et al. 2022), e.g. water movement is significantly less in deep water, up to 25-30 m, than in shallow water.

Furthermore, physical factors have a combined effect on the epibenthic organisms, e.g. the geomorphological characteristics of the site determine the influence of the water movement among microenvironments. Similarly, biotic interactions significantly influence the abundance and distribution of organisms in the deep environment (Bell et al. 2022, Canessa et al. 2022), such as competition for space. An important structuring mechanism in rocky reef communities in which organisms with different types of nutrition limit their growth rates. For example, photosynthetic organisms deprive feeders of suspended particulate organic matter, while suspension feeders deprive photosynthetic organisms of light (Ballesteros 2006).

This study allowed us to recognize which groups of organisms are typical of V and H substrates, as evidenced in the DCA. Differences in the slope of the substrate could cause variations of some abiotic factors such as light and sedimentation (Cocito et al. 2002, Irving & Connell 2002). Light incidence, substrate inclination (Antoniadou & Chintiroglou 2005), and sedimentation (Balata et al. 2005) are higher on horizontal surfaces than vertical ones, favoring an increase in photosynthetic organisms such as those that form algal turfs. Such factors could play a significant role in the structure of assemblages at Sacramento, as demonstrated in rocky (Bell et al. 2022) and biogenic reefs (Ballesteros 2006).

Sacramento had not been studied for three decades. Moreover, there is an information gap of almost 20 years on rocky reefs in the Mexican tropical Pacific region. Due to the serious threats provoked by human activity, it is essential to continue developing research to determine the processes that organize the assemblages of organisms.

Finally, this work represents the first quantitative reference of the epibenthic flora and fauna of a deep rocky reef in the Mexican tropical Pacific region. From this study, it is clear that focused exhaustive research is needed to determine the spatial and temporal patterns of assemblages of organisms and the mechanisms that structure them.

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